14th ICCRTS

"C2 and Agility"

The Ontology of Command and Control (C2)

Topic 2: Networks and Networking

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Abstract

The goal of the Department of Defense Net-Centric Data Strategy is to improve data sharing throughout the DoD. Data sharing is a critical element of interoperability in the emerging system-of-systems. Achieving interoperability requires the elimination of two types of data heterogeneity: differences of syntax and differences of semantics. This paper builds a path toward semantic uniformity through application of a disciplined approach to ontology. An ontology is a consensus framework representing the types of entities within a given domain and the relations between them. The construction of an ontology begins when a Community of Interest (COI) identifies its authoritative data sources (ADS), which are usually manifest in relevant doctrinal publications, glossaries, data dictionaries, and logical data models. The identified terms are then defined in relation to a common logical framework that has been designed to ensure interoperability with other ontologies created on the basis of the same strategy. As will be described, the Command and Control (C2) Ontology will include representations of a substantial number of entities within the Command and Control (C2) domain. If domain ontologies (e.g. Strike and Counterinsurgency) semantically align with the C2 Ontology, then a substantial barrier to systems interoperability is thereby crossed.

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The Content and Extensibility of the Core C2 Ontology

Command and Control (C2) signifies the disciplined pursuit of objectives of a sort which can be identified in any serious human endeavour, whether it be peacetime engineering, humanitarian disaster relief operations, or the conduct of war. The C2 Core Ontology will contain those important, relevant, and universally understood terms that need to be used with clarity when information is exchanged across a broad stakeholder base within the C2 domain. The content of the ontology should be general enough to accommodate joint, land, maritime, air, space, and cyber-space environment concerns. The terms must also apply across the spectrum of conflict, from stability and peace operations to insurgency and high-intensity conflict. Finally, the terms must also be extensible from the strategic level down through the operational to the tactical levels of war.

In order to ensure both broad applicability of the C2 Core Ontology and consistency of the domain-specific extensions constructed in its terms, it is necessary that the ontology should capture only those terms that are domain neutral in the sense that they apply to multiple sub-domains. To achieve these ends we must define the C2 Core domain and identify its boundaries to include only those general terms that pertain to a commander's ability to organize forces, understand the situation, plan for joint operations, decide on courses of action, direct subordinate commanders, and monitor progress.

Our position is that the C2 Core Ontology will form part of a larger suite of C2 Ontologies to be maintained in a modular fashion by specific COIs. The whole will provide a common semantics for the most frequently used C2 terms. Where terms such as

organization, plan, or assessment are currently defined using natural language expressions which cannot be processed logically, the C2 Core Ontology will provide the resources to define such terms in a logical way, enabling the use of computer resources for example in compilation, analysis and error-checking of data.

To achieve these ends there will be a Core C2 Ontology with a limited number of terms, and with modular sub-domain ontologies growing out therefrom (see Figure 1 below). Terms of the Core C2 Ontology will have rigorously defined semantic content. When sub-domain ontologies are defined on their basis, this will result in their being semantically integrated. The C2 Core Ontology itself will not seek to define terms that belong in sub-domain ontologies; rather, it will delegate the responsibility for such definitions to the associated Community of Interest (COI).

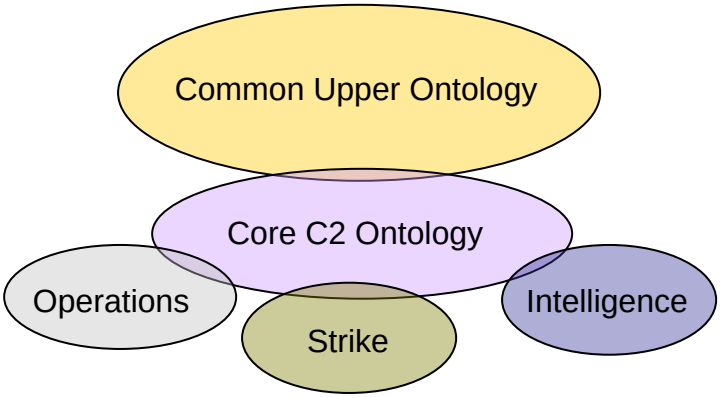

Figure 1. Examples of Modular Ontologies

The C2 Ontology Process: Analyze the Doctrinal Models and the Domain (Reality)

If we are to improve our understanding of Command and Control, then we will need to establish facts, develop testable theories, and instantiate these theories in models. In short, we must build a body of knowledge, gain experience, and develop expertise. To

accomplish this, we need to observe reality, intellectually develop models, and design and conduct experiments to calibrate and validate these models. This requires the collection of empirical evidence, the conduct of analyses, the publication of results, and the archiving of data. These tasks need to be performed in iterative fashion, with lessons learned in one cycle being carried forth to the next, and generalizable lessons learned by one COI being exportable to others.[1] To achieve these ends—which are parallel to ends already secured in the biomedical domain—the sorts of semantic interoperability provided by ontology technology are indispensable.[2]

To identify the high frequency terms of the C2 domain, which will form the C2 Core Ontology, we need to analyze the doctrinal models in light of the 6 components of C2. These components pertain to the commander's processes of:

- organizing available assets,
- gaining an understanding of the situation,
- planning for operations,
- making decisions,
- directing subordinate elements, and
- monitoring progress.

To this end, we analyzed three doctrinal C2 models—the Air Force OODA Loop, the Marine Corps C2 Model, and the Targeting Process (Figures 2, 3, and 4). More specifically, we analyzed the chronological process portrayed by each of the doctrinal

[1] David S. Alberts & Richard E. Hayes, Understanding Command and Control, CCRP Publication Series, 2006. pp. 14-15 www.dodccrp.org

[2] Barry Smith, et al., "The OBO Foundry: Coordinated Evolution of Ontologies to Support Biomedical Data Integration", *Nature Biotechnology*, 25 (11), November 2007, 1251 -1255.

models in light of the elements of C2 which pertain to the 6 just-listed components (see Figure 3 below).

Each doctrinal model starts with the commander and staff making observations about the operational environment they are faced with. This includes the mission, equipment, time available, terrain, troops available, and civilian population (METT-TC). The operations of both active observation and passive collection result in a deluge of data flowing into the C2 system. This data must be analyzed, prioritized, and processed into critical information, and ultimately fused into an understanding of the operational environment. The operational environment and the influx of information (intelligence) form the first necessary elements of the doctrinal C2 model here proposed.

Core C2 Ontology terms such as operational environment, organization, act of analysis, key task, purpose, effect, and critical information are chosen because they are general enough to extend to any situation across the spectrum of conflict. Furthermore, these terms apply at the strategic, operational, and tactical levels alike. They apply at the theater level of conflict, in any area of operations, at sea, and in the air. Each of these terms can then be used for C2 Ontology extension modules for sub-domains, where subject matter experts would be responsible for developing more specific sets of ontology terms e.g. for geo-spatial entities, types of military information, intelligence, and so forth.

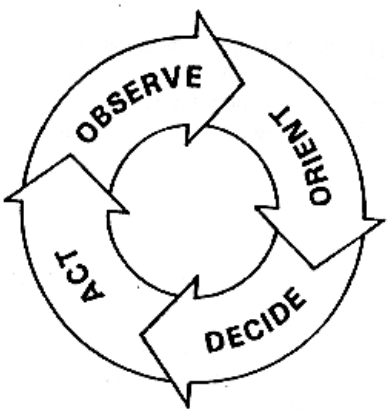

Figure 2. The Air Force OODA Loop

According to Marine Corps Doctrine, "Control takes the form of feedback—it is the continuous flow of information about the unfolding situation returning to the commander—which allows the commander to adjust and modify command action as needed. Feedback indicates the difference between the goals and the situation as it exists."[3] Therefore, terms pertaining to control include feedback loop, situation report, act of analysis, and decision point. Command-related terms pertain to the initiation of action by subordinate commanders; thus they include terms such as: delegation, intent, guidance, commander's vision, mission statement, key task, operation, and course of action. In short, control is seen as input into to the C2 system, and commands as outputs leading to actions by subordinate units (see figure 3 below).

[3] Marine Corps Doctrinal Publication 6, Command and Control

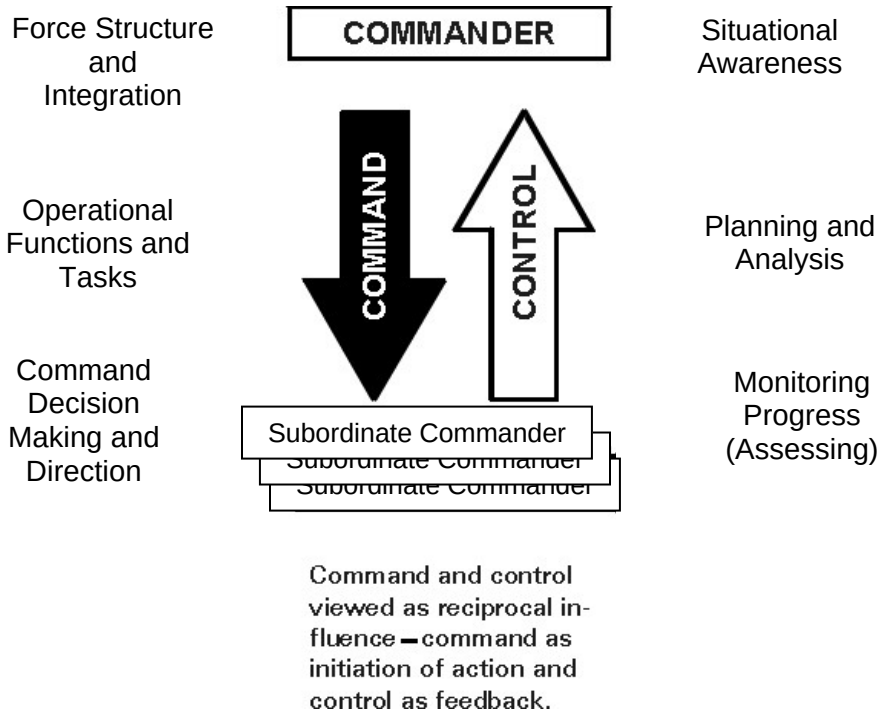

Figure 3. Marine Corps Doctrinal Publication 6
"Command and Control"

Delegating a mission, planning an operation, or developing a course of action are all purposive (goal oriented) activities, aimed at certain effects. Effects Based Operations (EBO) are defined as, "…operations conceived and planned in a systems framework that considers the full range of direct, indirect, and cascading effects—effects that may, with different degrees of probability, be achieved by the application of military, diplomatic, psychological, and economic instruments…"[4]

Commanders seek to attain some desired effect. To this end they assign task status to certain subordinate elements. The purpose of any task or mission is to achieve the desired end state, which drives the actions of subordinate commanders. Attaining the

[4] Paul K. Davis, Effects Based Operations: A Grand Challenge for the Analytical Community, Rand Report, 2001.

desired end state is thereby always more important than accomplishment of the assigned task or mission—i.e. the situation may change so that assigned tasks will no longer contribute to the desired end state. If the environment changes so that the assigned task or mission is no longer harmonious with the desired end state, then the subordinate commander is expected to change direction and choose another course of action. For this reason, the continuous assessment of lethal effects, non-lethal effects, and battle damage is a necessary element of the C2 process (see figure 4).

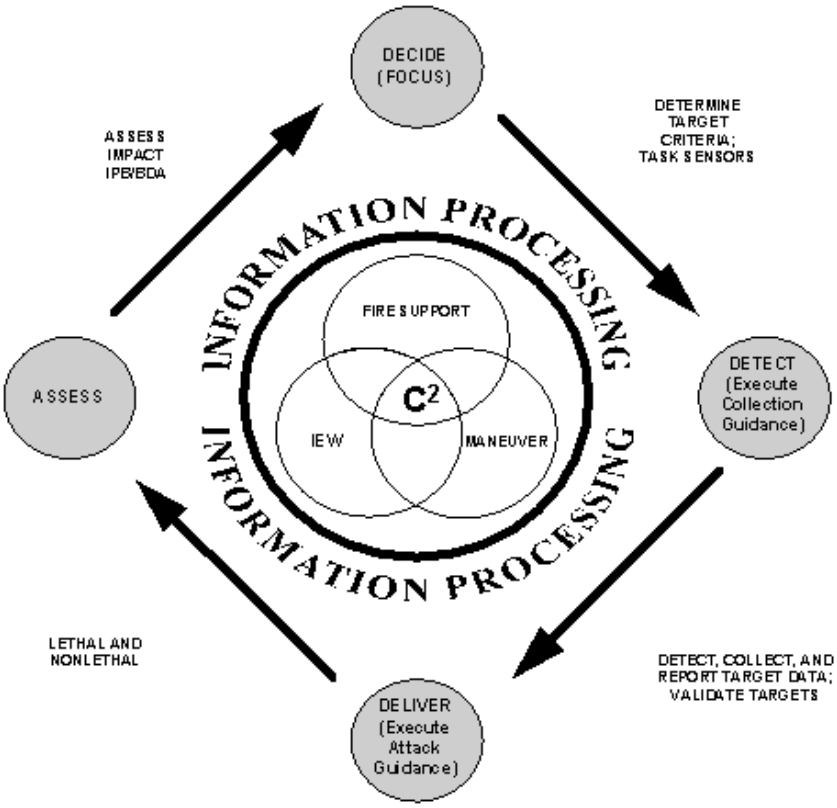

Figure 4. Targeting Process[5]

Figure 4. portrays the C2 process as being similar to the OODA Loop and the Marine Corps Doctrinal C2 model. In each case the C2 process is seen as a matter of the continuous

[5] Field Manual 6-20-10 Tactics, Techniques, and Procedures, for the Targeting Process

influx of information, observations to gain understanding, conducting of mission analysis, organization of available assets, decisions pertaining to probable courses of action, delegation of actions, and assessments pertaining to effects. This analysis is the result of years of historical and scientific analysis of actual cases. It, too, draws on numerous terms whose meanings have been standardized in use over time by joint and *ad hoc* staffs in operational settings.

C2 Sub-Domain Ontologies: Military Geo-Spatial Ontology, Information Ontology, Operations Ontology, and Effects Ontology

In this section we suggest four modular (sub-domain) ontologies to be developed as semantic extensions of the C2 Core Ontology. These suggestions represent only a sample of the modular (sub-domain) ontologies that will be needed. They are described in the order that they would fall in the C2 Cycle.

The C2 cycle begins with the commander and staff, set in an operational environment. An operational environment is a complex geo-spatial and geo-political entity with both physical and fiat geographic features. It is defined as a composite of the conditions, circumstances, and influences that affect the employment of capabilities and bear on the decisions of the commander.[6] The physical features in an operational environment include buildings, roads, population centers, bodies of water, hills, forests, etc. The fiat geographic entities in an area of operations include unit boundaries, limits of advance, areas of influence, no-fly zones, etc. The complex (dual) nature of military-geographic entities should be represented by their own modular ontology extending from the Core C2 Ontology.

Faced with the operational environment, the commander and staff must absorb massive quantities of information and process it into actionable intelligence. The

[6] Joint Publication 3-0, Joint Operations, 2008 (pg. 58).

processing of raw data into information, and ultimately into an understanding of the situation, is a complex process with its own specialized vocabulary. The Commander's staff, including intelligence analysts, are subject matter experts on the technologies of information and intelligence processing. Information comes to the command staff by way of situation reports, significant act (SIGACTS) reports, photographs, after action reviews, and intelligence reports. The massive flow of information must first be analyzed and categorized into critical and non-critical categories. For example, the commander's critical information requirements (CCIR) are the information requirements identified (by the commander) as being critical to timely decision-making required for mission success. The two key elements of CCIR are friendly force information requirements (FFIR) and priority intelligence requirements (PIR).[7]

The priority intelligence requirements (PIR) are the pieces of intelligence that the commander and staff need to understand the adversary or the operational environment.[8] There are over 40 types of intelligence, including acoustic intelligence, all-source intelligence, basic intelligence, civil defense intelligence, combat intelligence, communications intelligence, critical intelligence, current intelligence, departmental intelligence, domestic intelligence, electronic intelligence, electro-optical intelligence, foreign intelligence, foreign instrumentation signals intelligence, general military intelligence, human resources intelligence, imagery intelligence, joint intelligence, laser intelligence, measurement and signature intelligence, medical intelligence, merchant intelligence, military intelligence, national intelligence, nuclear intelligence, open-source intelligence, operational intelligence, photographic intelligence, political intelligence,

[7] Joint Publication 3-0, Joint Operations (2008) p. III-11
[8] Joint Publication 5-0, Joint Planning (2006) p. GL-20

radar intelligence, radiation intelligence, scientific and technical intelligence, security intelligence, strategic intelligence, tactical intelligence, target intelligence, technical Intelligence, technical operational intelligence, terrain intelligence, and unintentional radiation intelligence.[9] The complex nature of battlefield intelligence, too, requires a modular information and intelligence ontology that will align with the Core C2 Ontology.

The commander and staff use the CCIR and PIR to make informed decisions pertaining to what courses of action to adopt. In other words, the commander and staff must decide what types of tasks and operations (missions) their subordinate units will be assigned. A military operation is defined as a military action, or the carrying out of a strategic, operational, tactical, service, training, or administrative military mission. A second definition of military operation is the process of carrying on combat, including movement, supply, attack, defense, and maneuvers needed to gain the objectives of any battle or campaign.[10] This definition indicates that there are numerous types and sub-types of operations, which take place across a spectrum of conflict, from stable peace to unstable peace, and from insurgency to full scale war. Operations can be offensive, defensive, stabilizing, or enabling in nature (see figure 5 below). Furthermore, operations take place on land, at sea, in the air, in outer space, and in cyber-space. The complexity of military operations makes a strong case in favor of a modular Operations Ontology that would semantically align with the Core C2 Ontology and other related sub-domain ontologies.

[9] Joint Publication 2-0, Joint Intelligence (2007)
[10] Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms (2001) p. 397

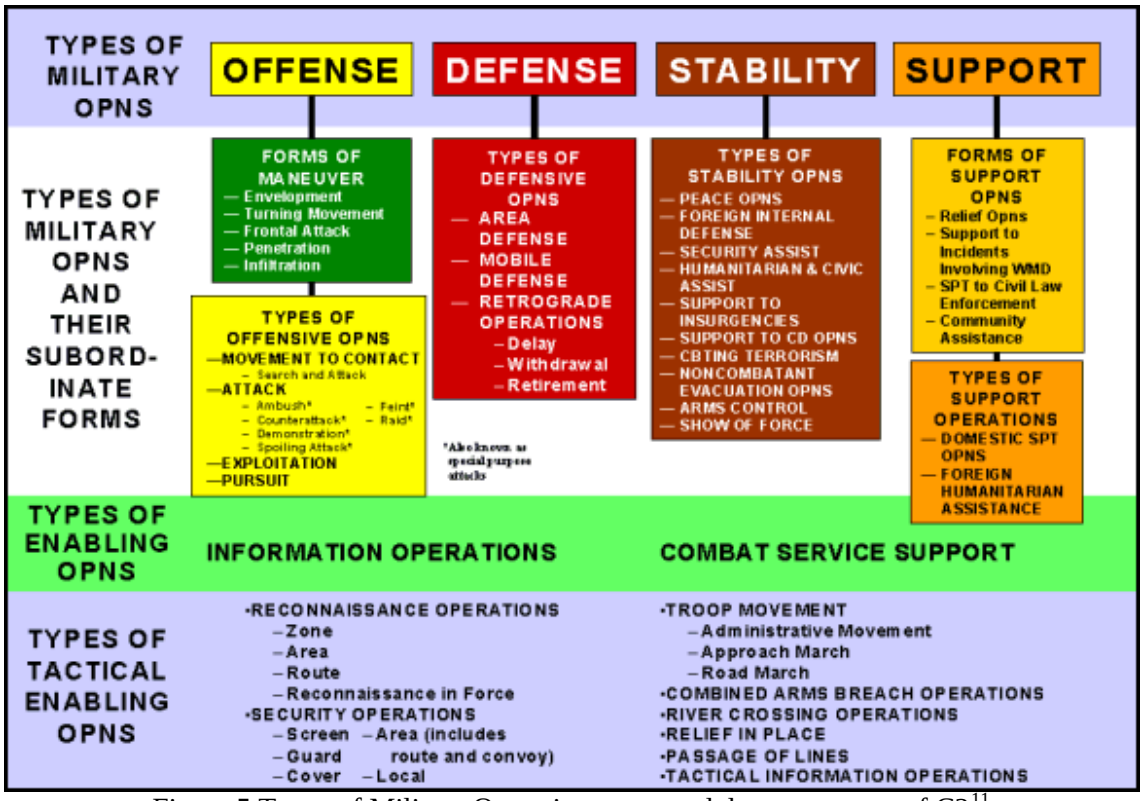

Figure 5 Types of Military Operations as a modular component of C2[11]

The fourth modular ontology we suggest pertains to effects. The commander and staff select a course of action, mission, or a specific type of operation in order to attain a desired end state—i.e. the set of required conditions that defines achievement of the commander's objectives.[12] The commander's intent is a concise expression of the purpose of the operation and the desired end state.[13] The desired end state can be described in terms of the resulting effects—an Effects Based Operations Ontology would describe the different types of effects and measures of effectiveness (MOE's). For example, Effects Based Operations can first be categorized into physical or psychological

[11] Field Manual 3-90, Tactics (2001) p. 2-2
[12] Joint Publication 3-0, *Joint Operations* (2008) p. GL-13
[13] Joint Publication 3-0, *Joint Operations* (2008) p. GL-9

effects, and each of these categories has several distinct sub-categories of their own—e.g. direct, indirect, and cascading effects (see figure 6 below).

Physical	Psychological (Reason/Belief)
Destruction	Chaos / Entropy
Physical Attrition	Foreclosure • Passive • Active
Chaos / Entropy	Shock
	Psychological Attrition

Figure 6 Types of Effects[14]

Conclusion

In this essay we present a process for constructing a concise, modular, and extensible Core C2 Ontology, based upon doctrinal models and a realist perspective. The ontology we propose would contain terms that need to be exchanged in any command and control (C2) environment. The content and structure of the ontology would apply to joint, land, sea, air, space, and cyber operations. Terms within the ontology must apply across the spectrum of conflict, from stability and peace operations to insurgency and high-intensity conflict. The terms must also be extensible from the strategic level of war through the operational to the tactical levels of war.

If done properly, the Core C2 Ontology will be an extension of the common upper ontology, and it will extend to various C2 related sub-domain ontologies. To these ends, it is important to identify the correct break-points for the C2 Core Ontology, capturing

[14] Edward A. Smith, *Effects Based Operations: Applying Network Centric Warfare in Peace, Crisis, and War,* Command and Control Research Program Publication Series (2006) p. 257

only those terms that are universal C2 terms, allowing COIs to develop modular extensions consistent with the C2 Core Ontology and incorporating specialized terms needed in specific domains.

Our position is that the resultant suite of C2 Ontologies built around the C2 Core Ontology as common element will be a concise, powerful, and modular resource, which will provide common semantics for all of the most frequently used C2 terms. Some of the terms in the Core C2 Ontology will act as the nexus for—i.e. be extensible in the creation of—the sub-domain (modular) ontologies. A sample list of candidate terms for inclusion in the Core C2 Ontology is found in figure 7 below. Development of the related sub-domain ontologies would be delegated to the aligned Communities of Interest (COI).

1. Situational Awareness	**2. Planning and Analysis**	**3. Operations/Tasks**
Area of Influence	Act of Planning	Operation
Area of Interest	Act of Analysis	Mission
Area of Operations	Act of Visualization	Engagement
Operational Environment	Military Objective	Essential Task
4. Force Structure	**5. Deciding and Directing**	**6. Assessment**
Act of Organizing	Act of Deciding	Act of Assessment
Military Organization	Decision Point	Phase Line
Criminal Organization	Guidance	Effect
Humanitarian Organization	Directive	End State
Governmental Organization	Fragmentary Order	Situation Report

Figure 7. a sampling of candidate terms for the Upper C2 Core Ontology

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Paul K. Davis, Effects Based Operations: A Grand Challenge for the Analytical Community, Rand Report, 2001

Barry Smith, et al., "The OBO Foundry: Coordinated Evolution of Ontologies to Support Biomedical Data Integration", *Nature Biotechnology*, 25 (11), November 2007, 1251 - 1255.

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Joint Publication 3-13.1 Joint Doctrine for Command and Control Warfare (C2W) (1996)

Joint Publication 3-0, Joint Operations (2008)

Joint Publication 5-0, Joint Planning (2006)

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Command and Control (C2) Ontology

(Paper 159)

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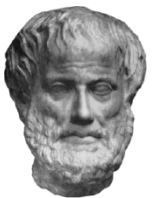

Begin with the Low-Hanging Fruit

- Getting to the Low-Hanging Fruit
  - Reliable Data Sources
  - Good C2 Models
  - C2 Experience
  - Apply 10/90 rule
  - Use “Best Practices”

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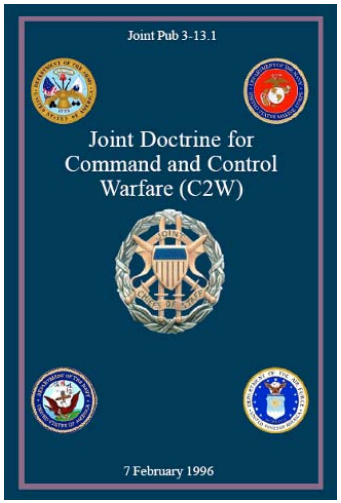
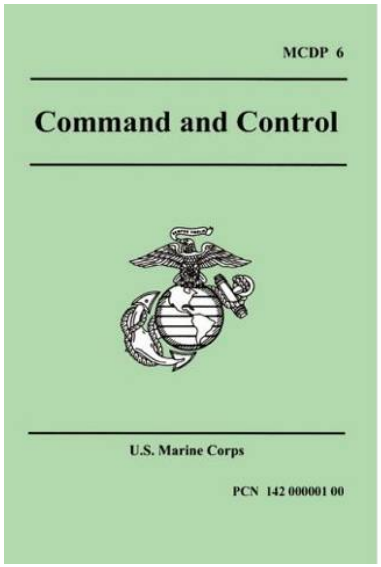
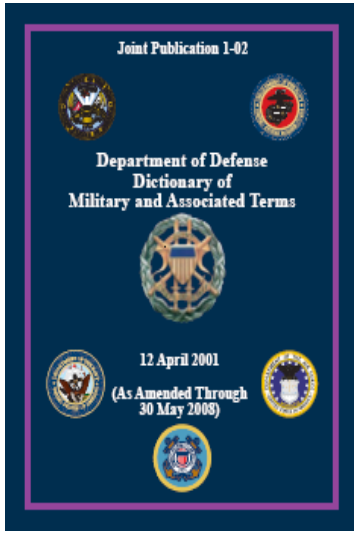
Some Sources…

- JP 5-0 Joint Operation Planning
- JP 1-02 DoD Dictionary of Military and Related Terms
- JP 3-13.1 Joint Doctrine for Command and Control
- JP 3-0 Joint Operations
- FM 3-0 Operations



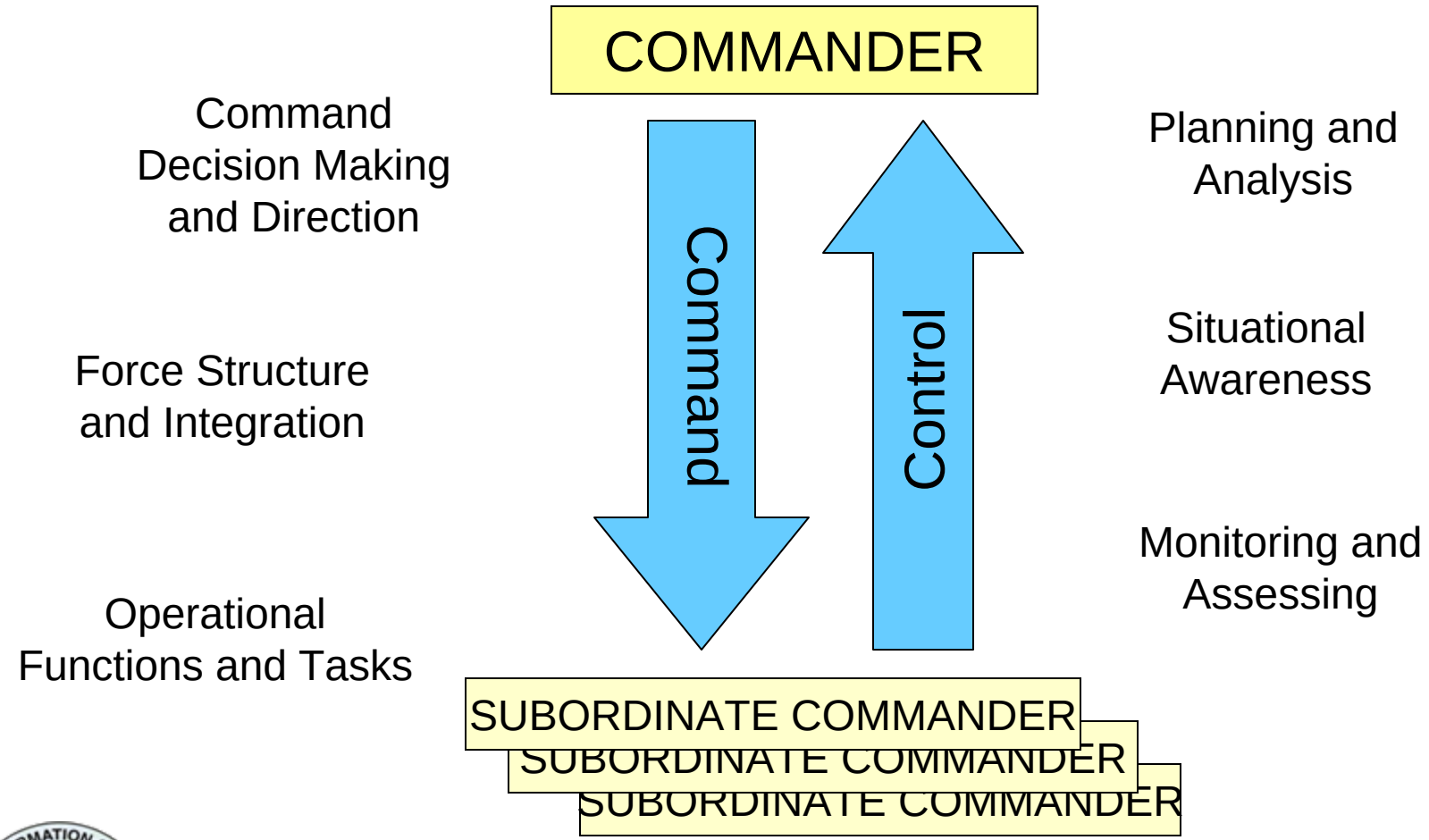




The Elements of C2

- C2 consists of:
  - Force Structure, Integration, Organization
  - Operational Functions and Tasks
  - Situational Awareness
  - Planning and Analysis
  - Decision Making and Direction
  - Monitoring Progress (Assessing)
- C2 terminology will result from these elements
- Lets consider them individually…

USMC Command and Control Model



Source: USMC Doctrinal Publication 6

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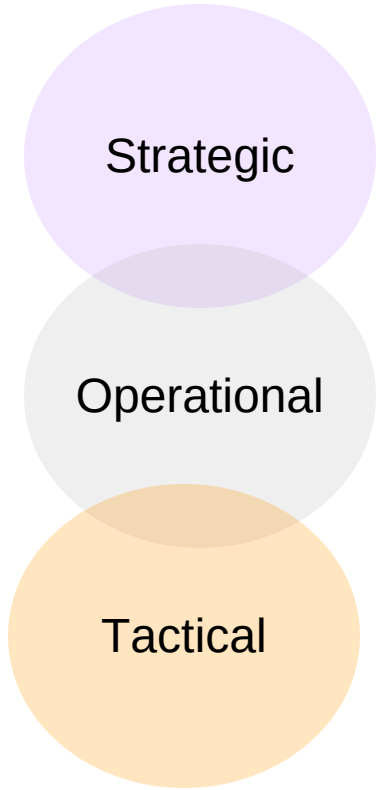
Top Down, Bottom Up



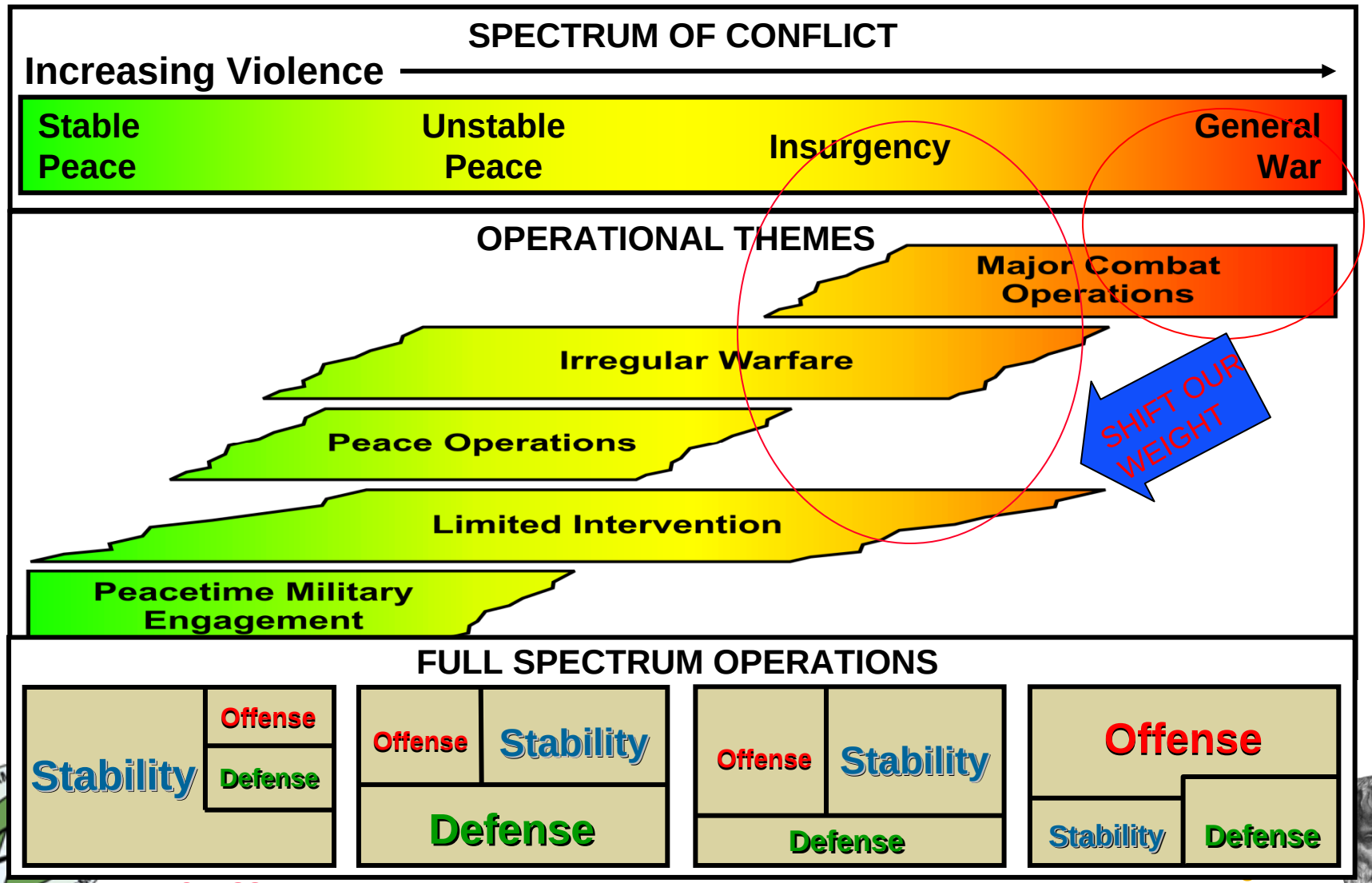
Devising Strategy

Operational Planning and Decision Making

Tactical Messaging

Call For Fire, MEDEVAC, SITREPS…

FM 3-0, Army Full Spectrum Operations

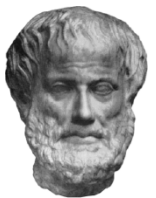


Force Structure, Integration, Organization

UCore-SL	C2 Extension
Act	ActOfOrganizing
Organization	Civil Organization
Organization	Criminal Organization
Organization	Governmental Organization
Organization	Humanitarian Organization
Organization	Military Organization

Operational Functions (Tasks)

UCore-SL	C2 Extension
Military Event	Battle
Military Event	Campaign
Military Event	Engagement
Task	Essential Task
Task	Mission
Military Event	Operation



Situational Awareness

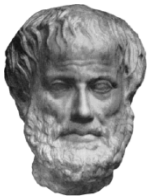
UCore-SL	C2 Extension
Act	Act of Analysis
Geospatial Region	Area of Influence
Geospatial Region	Area of Interest
Geospatial Region	Area of Operations
Control Feature	Boundary
Objective Specification	Criminal Objective Specification
Objective Specification	Governmental Objective Specification
Information Content Entity	Message
Geopolitical Entity	Population Center
Information Content Entity	Report

Planning and Analysis

UCore-SL	C2 Extension
Act	Act of Plan Creation
Act	Act of Plan Revision
Plan	Battle Plan
Plan	Campaign Plan
Objective	Criminal Objective
Objective	End State
Objective	Governmental Objective
Objective	Military Objective
Objective Specification	Military Objective Specification
Plan	Operation Plan

Decision Making and Direction

UCore-SL	C2 Extension
Act of Communication	Act of Order Issuance
Document	Battle Plan Document
Document	Campaign Plan Document
Task Specification	Fragmentary Order
Information Content Entity	Guidance
Task Specification	Operation Order
Document	Operation Plan Document
Task Specification	Warning Order
Document	Warning Order Document



Monitoring Progress

UCore-SL	C2 Extension
Act	Act of Assessment
	Effect
	Measure of Effectiveness
Control Feature	Phase Line
Geospatial Region	Sector
Information Content Entity	Situation Report
Control Feature	Target

Tactical Level Messages

UCore-SL	C2 Core	Message
Objective: An Information content entity that represents the content of an objective specification	**Mission:** an Objective of a military Plan.	**Fire Mission:** a mission given to a fire unit as part of a definite plan.
Geospatial Region: a physical entity that is a spatial region at or near the surface of the Earth	**Location:** A geospatial region that is denoted by a geospatial measurement datum.	**Target Location:** A Location occupied by an entity at a given time that is denoted by the measurement output of some targeting event.
Geospatial Region: a physical entity that is a spatial region at or near the surface of the Earth	**Location:** A geospatial region that is denoted by a geospatial measurement datum.	**Facility Location:** A Location occupied by an entity at a given time that is denoted by the measurement output of some mapping event.

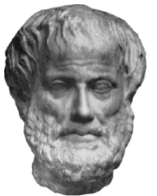
Tactical Level Messages

UCore-SL	C2 Core	Message
Information Content Entity: An Entity which consists of information and which inheres in some physical entity (i.e. an information bearing entity)	**Identifier:** An information content entity that denotes a specific entity instance.	**Target Identifier Abstract:** An identifier that denotes the target of some targeting event.
Information Content Entity: An Entity which consists of information and which inheres in some physical entity (i.e. an information bearing entity)	**Identifier:** An information content entity that denotes a specific entity instance.	**Warhead Identifier:** An identifier that denotes a warhead.

Other Doctrinal C2 Terms…

- Commander's Intent
- Purpose
- Tactical Problem
- Operational Environment
- Act of Visualization
- Common Operating Picture
- Operational Design
- Element of Combat Power
- Effect
- Commander's Guidance
- War-fighting Function
- Priority Information Requirement (PIR)
- Decision Point
- Marine Corps Planning Process (MCPP)
- Military Decision Making Process

Backup Slides



Sample Terms

UCore-SL Term	C2 Extension Term
Item of Materiel Equipment Vehicle Aircraft Replacement Part	Military Vehicle Military Aircraft Military Close-air-support Aircraft Civilian Aircraft Military Equipment Replacement Part
Military Event	Military Campaign An Operation is part of a Campaign A Battle is part of an Operation An Engagement is part of a Battle
Organization	Military Organization Governmental Organization Humanitarian Non-Governmental Organization Criminal Organization

Task and Purpose

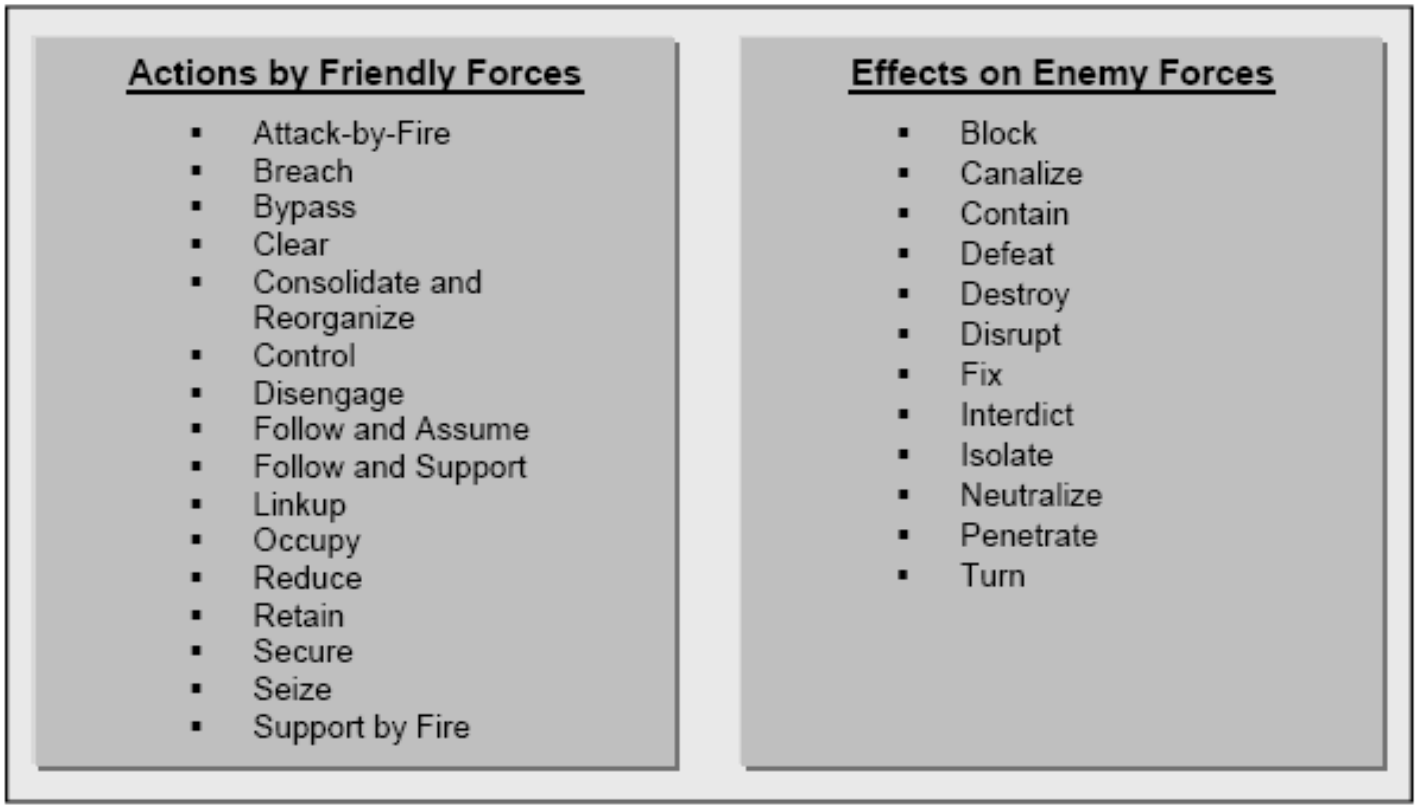
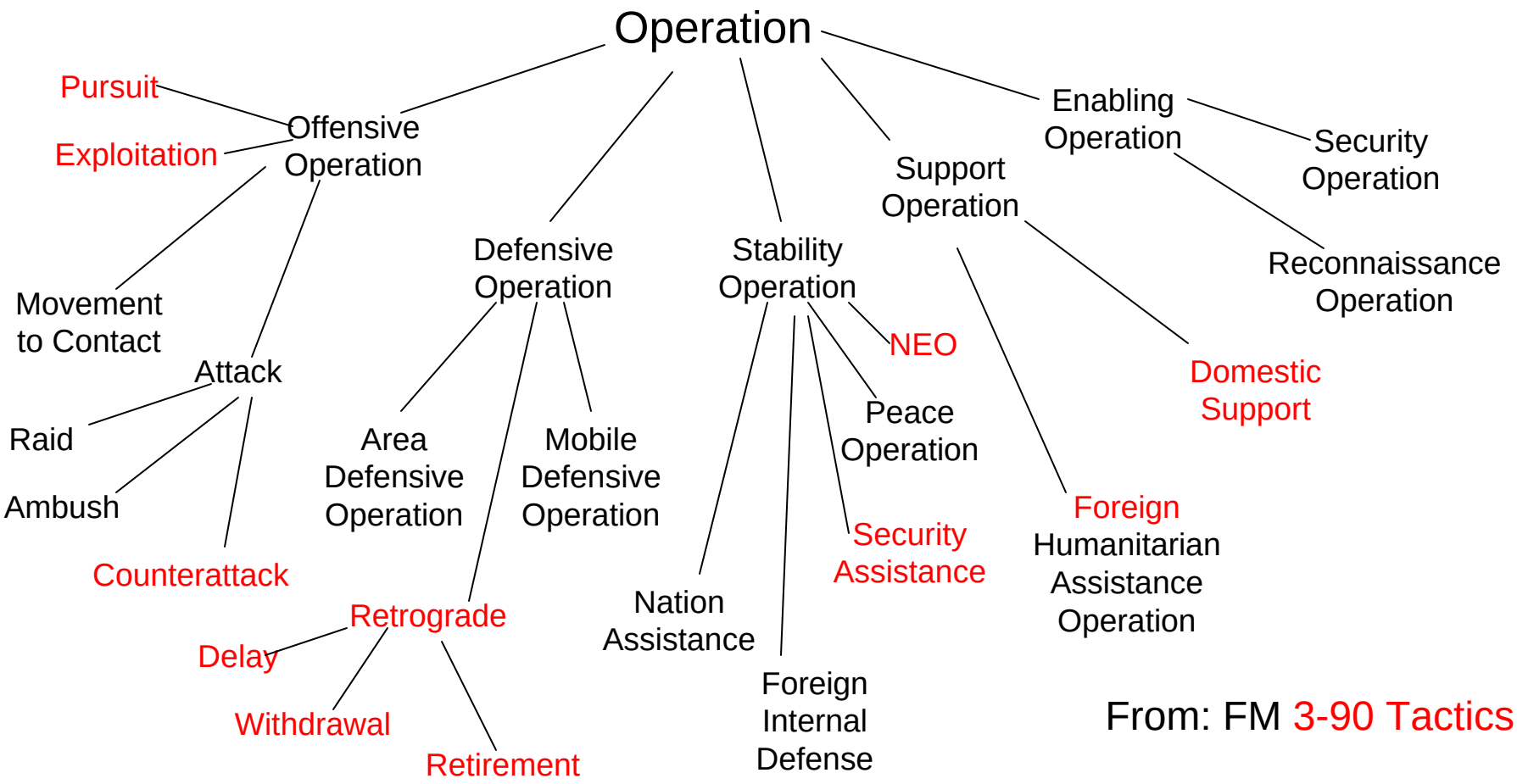


Figure 3-7. Mission Tasks

Relations Ontology

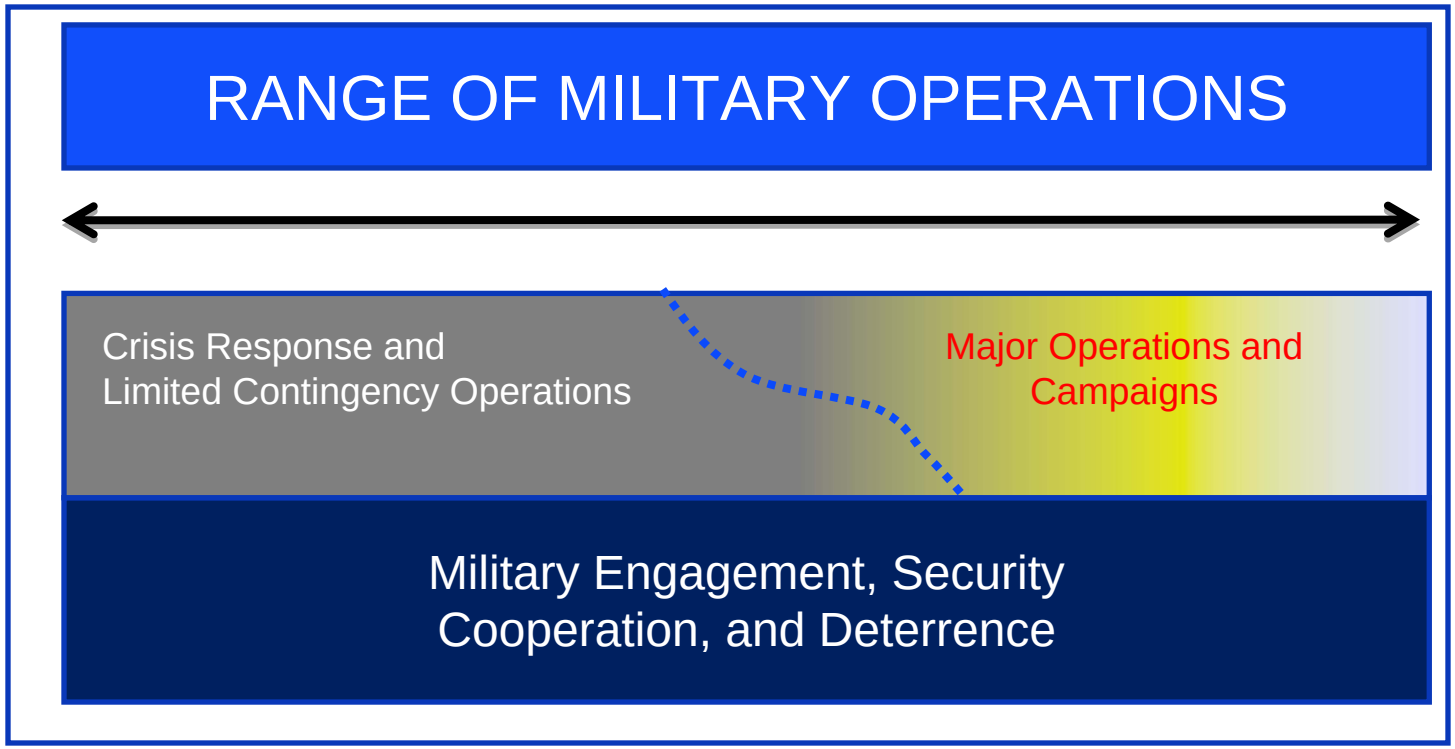
- *is_a*
- *Instantiates*
- *continuant_part_of*
- *occurrent_part_of*
- *region_part_of*
- *adjacent_to*
- *contained_in*
- *contains*
- *located_in*
- *overlaps*
- *has_participant*
- *has_agent*
- *specifically_inheres_in*
- *generically_inheres_in*
- *quality_of*
- *function_of*
- *role_of*
- *disposition_of*
- *realized_by*
- *towards*
- *derives_from*
- *transformation_of*
- *preceded_by*
- *lacks_part*

Types of Military Operations (Previous Army)



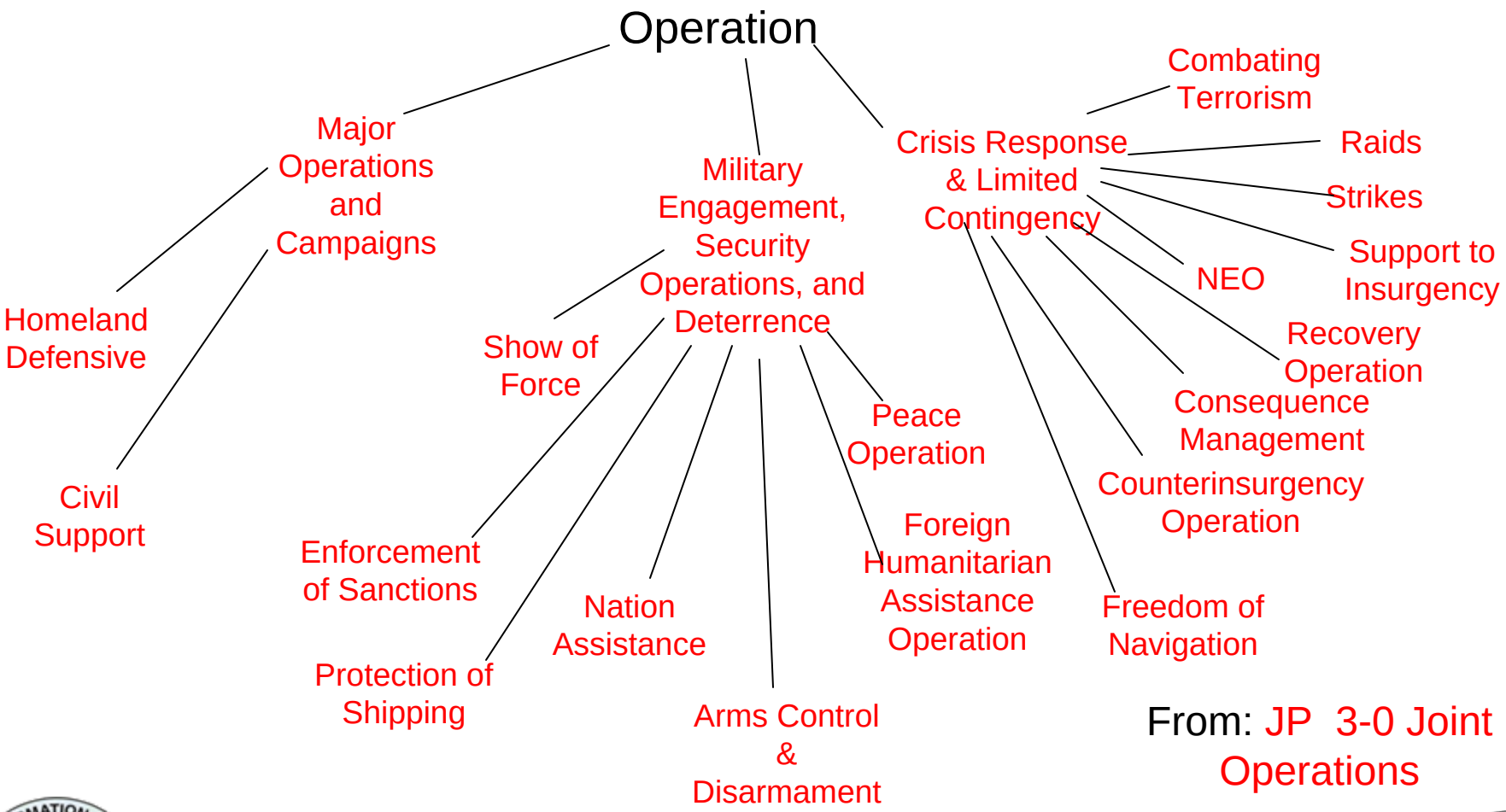
From: FM 3-90 Tactics

Joint Military Operations



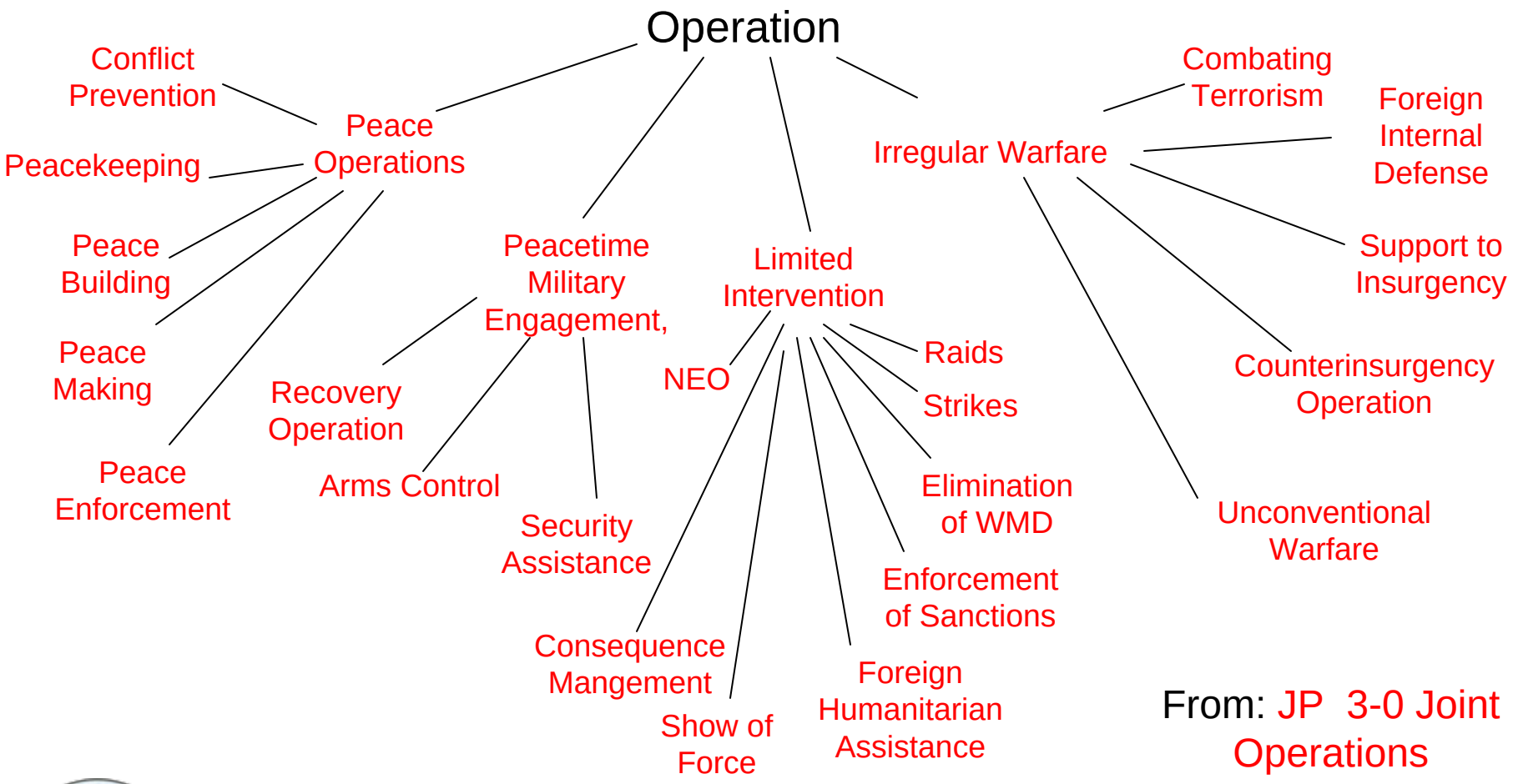
JP 3-0, Joint Operations

Types of Military Operations (Joint)



From: JP 3-0 Joint Operations

Types of Military Operations (Army FM 3-0)



From: JP 3-0 Joint Operations